MINERvA

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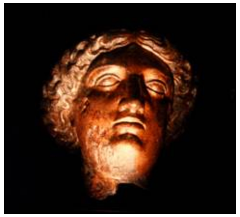
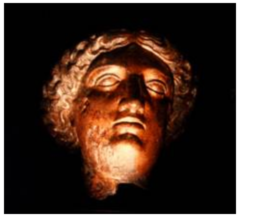
Fermilab
Physics Advisory Committee Meeting
January 22, 2014

Outline



- MINERvA Overview
- Brief History of MINERvA
- Low Energy Run Physics Output
- Medium Energy Physics Goals
- Need for Statistics in Medium Energy Run
- Need for Anti-neutrinos in ME Run
- Special Run Request

Physics Overview

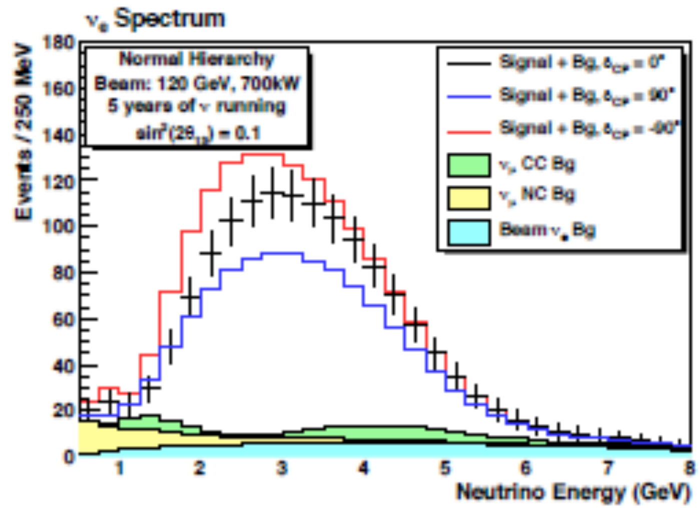


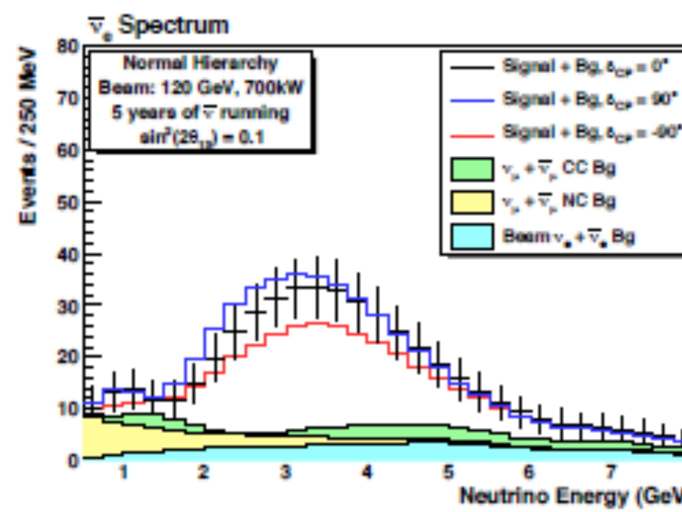
- MINERvA is studying neutrino interactions in unprecedented detail on a variety of different nuclei – He, C, CH_2, H_2O,Fe,Pb
- Low Energy (LE) Beam Goals:
  – Study both signal and background reactions relevant to oscillation experiments (current and future)
  – Measure nuclear effects on exclusive final states
    - As function of a measured neutrino energy
    - Study differences between neutrinos and anti-neutrinos
  – Measure exclusive channel cross sections and dynamics

- Medium Energy (ME) Beam (NOvA) Goals:
  – Structure Functions on various nuclei
  – Study high energy feed-down backgrounds to oscillation experiments

Oscillation Physics and Neutrino Interactions

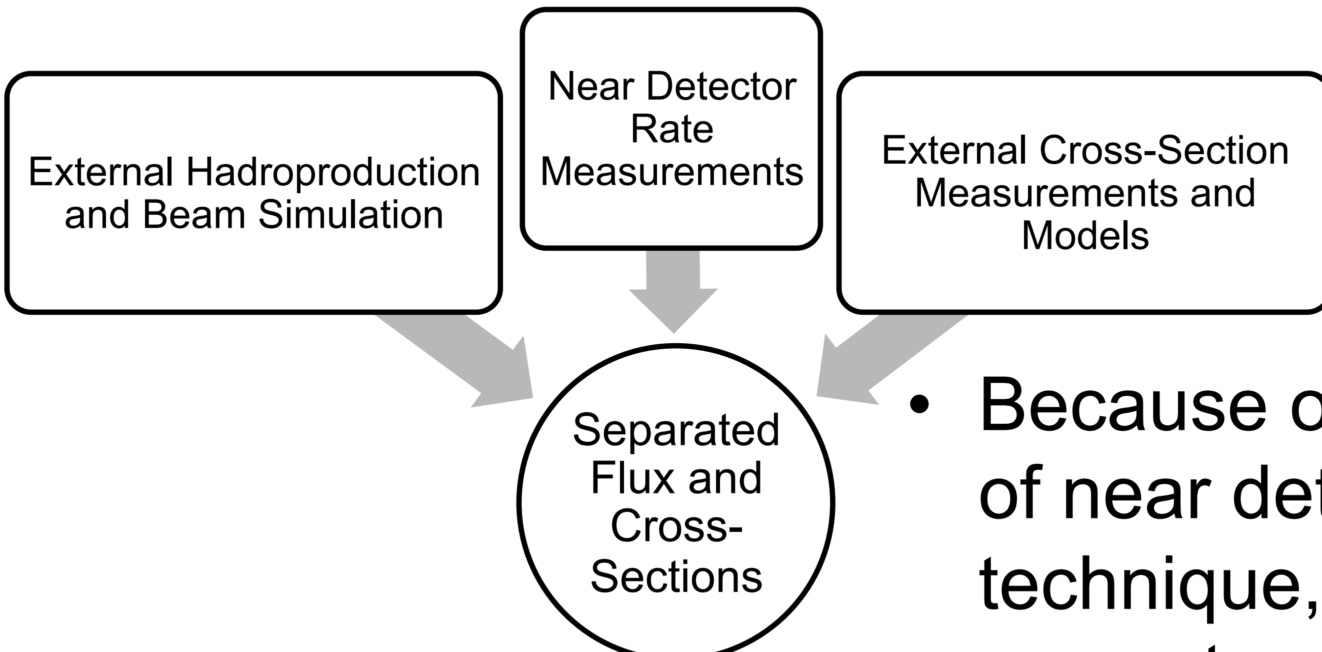
- Possible LBNE Far Detector Event Spectra shown above, Red and Blue are difference between two extremes of CP violation (±90^{o})
- Now Imagine what a Near Detector sees:
  - Most events are muon neutrino events
  - Intrinsic Electron Neutrino Events have completely different spectrum
  - Background Electron Neutrino events are coming from different mix of interactions
  - Still don’t have a “true neutrino energy”, can only measure final state particles
  - How can we get past this?
    - Have to break the degeneracy between flux and cross sections





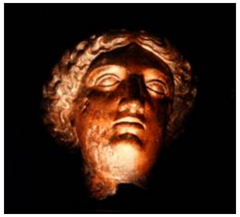
Breaking the Flux/Cross Section Degeneracy

- Experiments have a more or less universal scheme for using the near detector data to get flux and cross-section



- Because of limitations of near detector technique, these rely on accurate models:
- Enter MINERvA

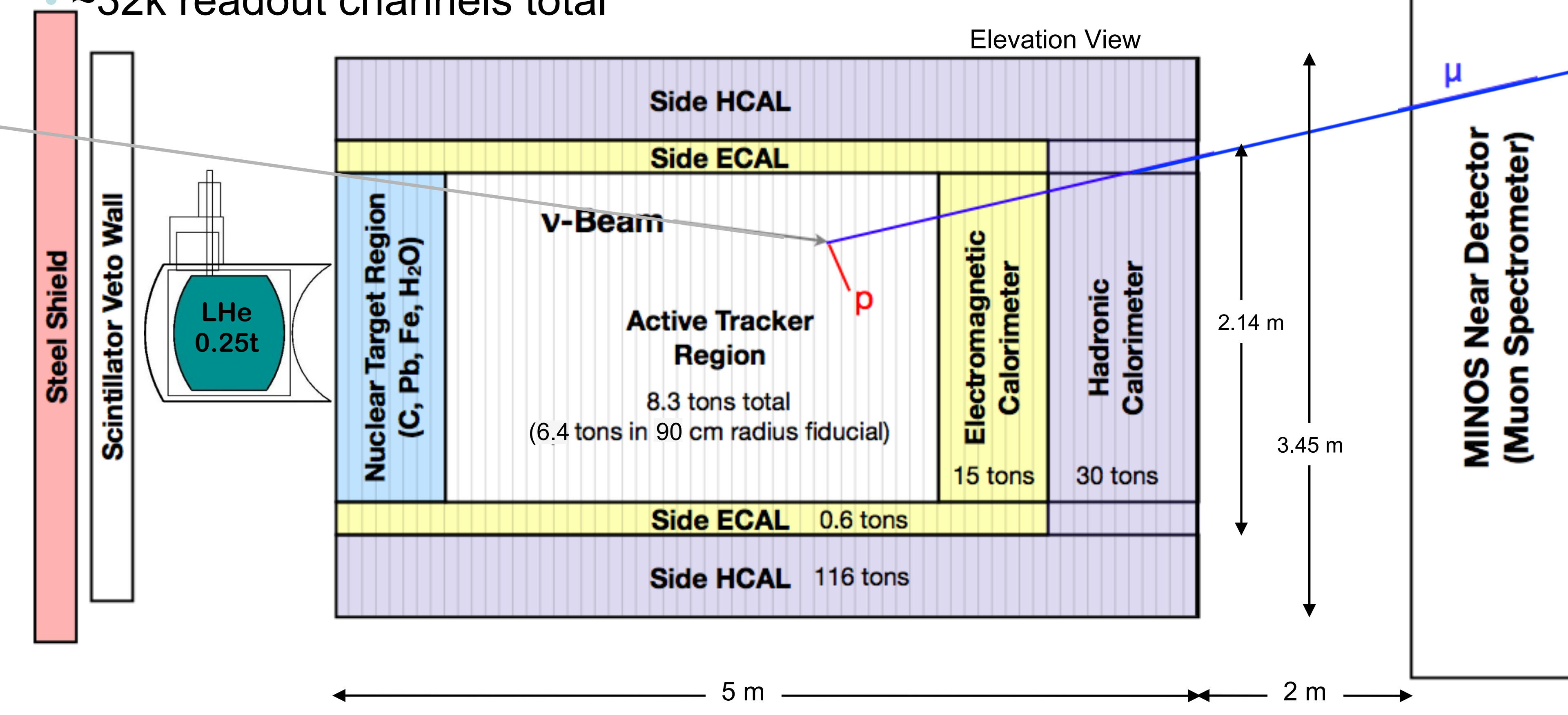
History of MINERvA Run Plan



- Proposal to do MINERvA Experiment: February 2004 arXiv:hep-ex/0405002
  - 4 year run, propose to accumulate 15E20POT
  - Mix of Low and High Energy runs, with ν and anti-ν in both tunes
- Stage I Approval: April 2004
- MINERvA CD-0: June 2006
- MINERvA CD-1,2,3a: March 2007
  - Technical Design Report: “1 year running parasitically with MINOS, 3 years running parasitically with NOvA, 4e20 POT per year” (ν only)
    - 4E20 POT in LE beam
    - 12E20 POT in ME beam
  - Medium Energy Beam considered the main source of events
- MINERvA Detector and solid targets Complete: March 2010
- Low Energy Run ends: April 2012, integrated 4E20POT, ν and anti-ν
- Medium Energy Run projection: 3E20 POT per year for first 2 years
  - Would take 3-4 years to get to 12E20

MINERvA Detector

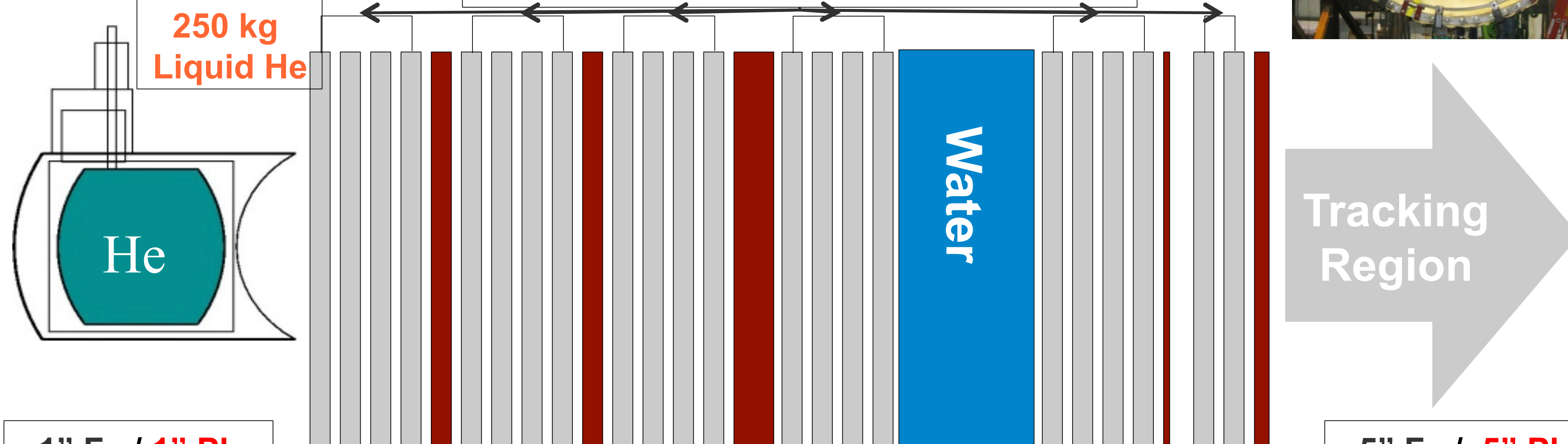
- Detector comprised of 120 “modules” stacked along the beam direction
- Central region is finely segmented scintillator tracker
- ~32k readout channels total



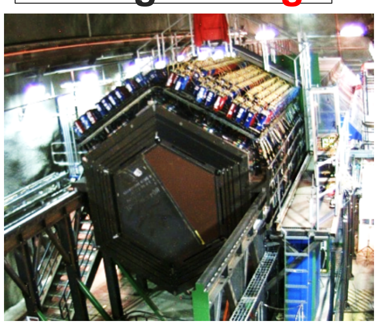
Nuclear Targets

Active Scintillator Modules

250 kg
Liquid He

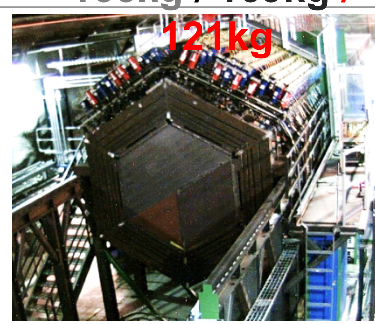


1” Fe / 1” Pb
323kg / 264kg

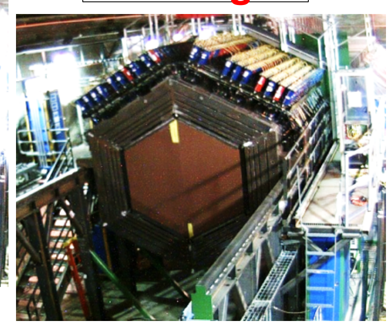


1” Pb / 1” Fe
266kg / 323kg

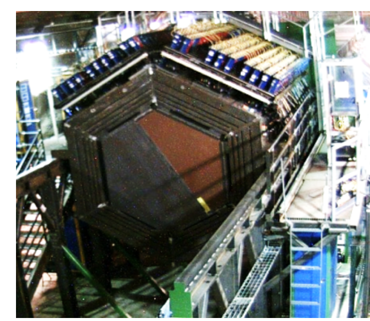
3” C / 1” Fe / 1” Pb
166kg / 169kg / 121kg



0.3” Pb
228kg

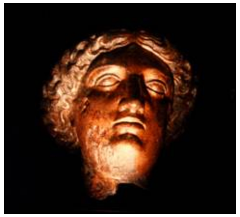


.5” Fe / .5” Pb
161kg/ 135kg



LOW ENERGY RUN RESULTS

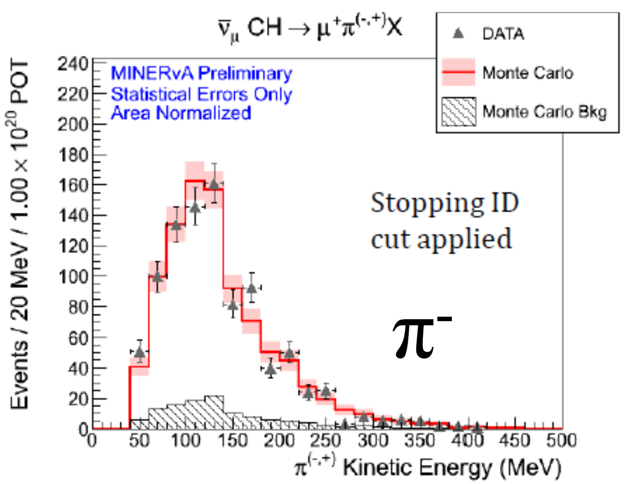
Low Energy Physics Highlights (so far)

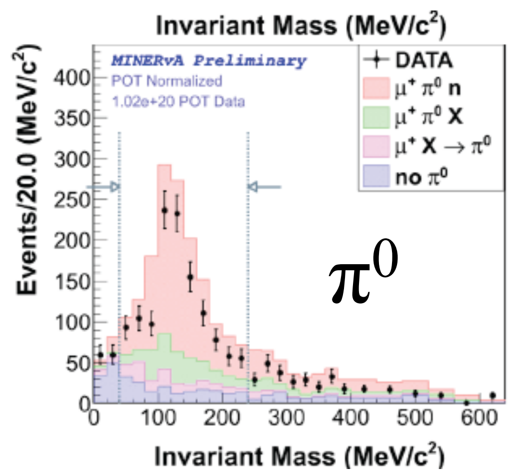


- At June PAC, you heard about the Quasi-elastic results in neutrino and antineutrino mode. These were published in back to back PRL's in June 2013
  - PRL 111, 022502 & PRL 111, 022501
- Detector NIM Paper accepted and will appear in print shortly
  - L. Aliaga *et al*, 10.1016/j.nima.2013.12.053
- Currently two results are released, three new papers are in progress:
  - October 2013 release: nuclear target cross section ratio results
  - December 2013 release: Measurement of the NuMI flux using neutrino-electron scattering interactions
  - February 2014 release: single pion production in neutrino scattering

Upcoming LE Results

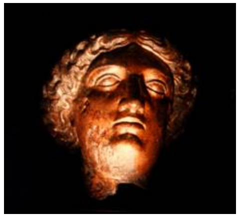
- In the very near future, we expect new results on charged current resonant and coherent pion production
  - Major background to oscillation experiments





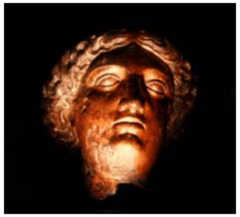
- We will also expand our quasi-elastic measurements
  - Ratio compared to total cross section
  - Studies of events with identified proton
  - Studies of events on nuclear targets

Impact of LE Results



- We do know some of the uses of the results because of interactions with other experiment collaborations or theory groups
- T2K uses external data (mostly MiniBooNE so far) to down-select alternative models and to fit parameters in those models. Near detector constraint is applied after this model constraint step.
  - Now fitting MINERvA's CCQE results to select multi-nucleon model. Planned for 2014 oscillation analysis.
  - Plan to use CCπ^+ MINERvA data beginning in February when it is released, and CCπ^0 when it is available
- Two main efforts from theory side asking questions about our data
  - Extended kinematics multi-nucleon calculation (Nieves et al)
  - Groups interested in final state interactions, e.g., GiBUU

“LE” Topics in NOvA era beam



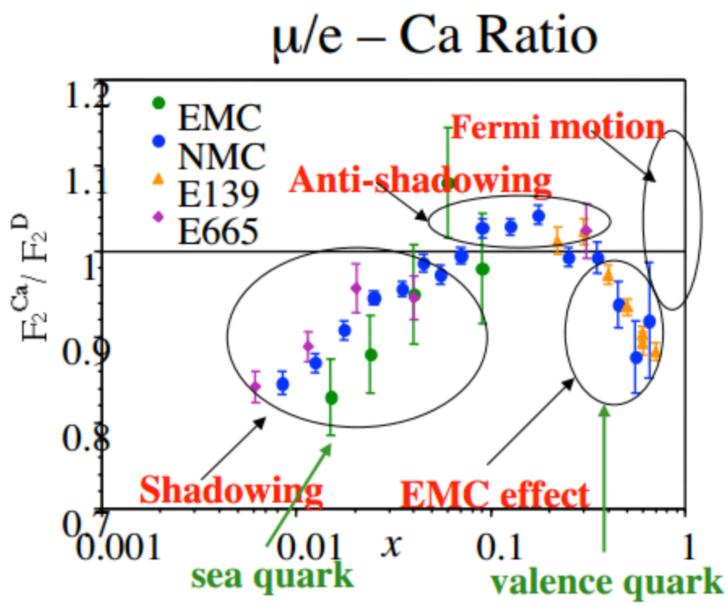
- Most of the measurements we’ve made in the low energy beam can be repeated in the medium energy beam without too much addition to background from high energy feeddown
  - LE beam already has a significant high energy tail, so have had to develop background rejections already to identify exclusive states
- Interests vary depending on topic
  - For flux integrated cross-sections (CCQE, pion production), integrating over a different flux is very useful. Different regions of momentum and energy transfer to target appear at different muon energy and angle.
  - For statistics challenged measurements (coherent scattering, exclusive states from nuclear targets) increased statistics will dramatically improve measurement.

EXAMPLE MEDIUM ENERGY PHYSICS GOALS

1. “EMC” effect with neutrinos
2. Coherent scattering from nuclear targets

Nuclear Effects in Inelastic Neutrino Scattering

- Nuclear Effects change momentum, and even identity of particles that leave the nucleus in a neutrino interaction
- These in turn will effect the measured or “visible” energy in a neutrino experiment
- Oscillation experiments will rely heavily on the measured visible energy
  - Event selection
  - Measurements! ($\Delta m^2 L/E_\nu$)
- Right now neutrino event generators have to rely on measurements from charged leptons
  - NO NEUTRINO DATA on these ratios prior to MINERvA
  - Field is still confused about these effects, need new probes



CERN COURIER

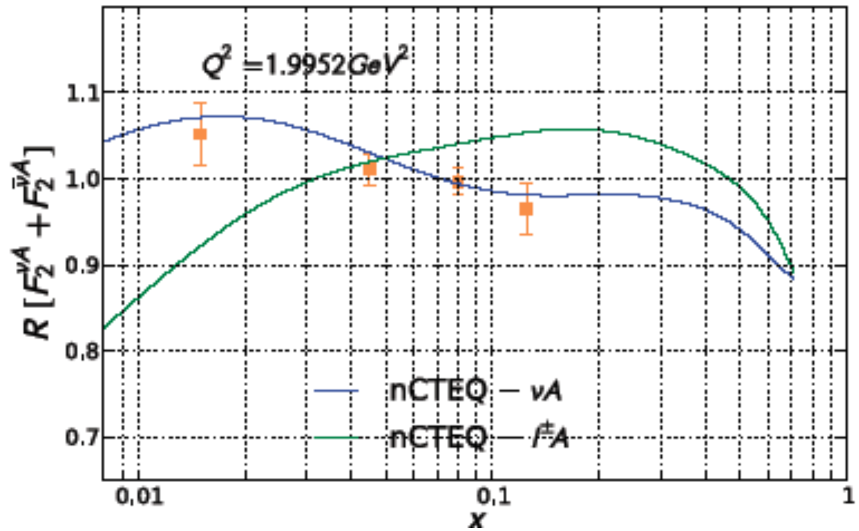
Apr 26, 2013

The EMC effect still puzzles after 30 years

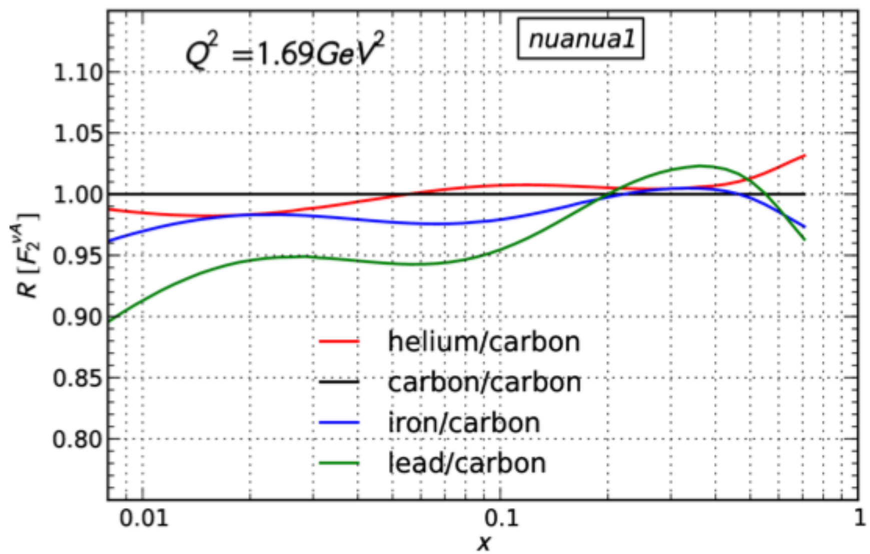
Thirty years ago, high-energy muons at CERN revealed the first hints of an effect that puzzles experimentalists and theorists alike to this day.

CTEQ Predictions from Charged Lepton and NuTeV data:

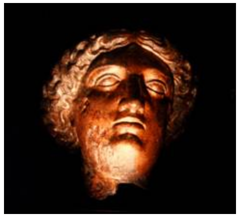
- CTEQ tries to fit for nuclear effects by comparing NuTeV structure functions on Iron to predicted “n+p” structure functions and comparing to predictions from charged lepton effects:
  - charged lepton fit undershoots low-x ν data & overshoots mid-x ν data
  - low-Q^2 and low-x ν data cause tension with the shadowing observed in charged lepton data
  - K. Kovarik et al. Phys.Rev.Lett. 106:122301,2011



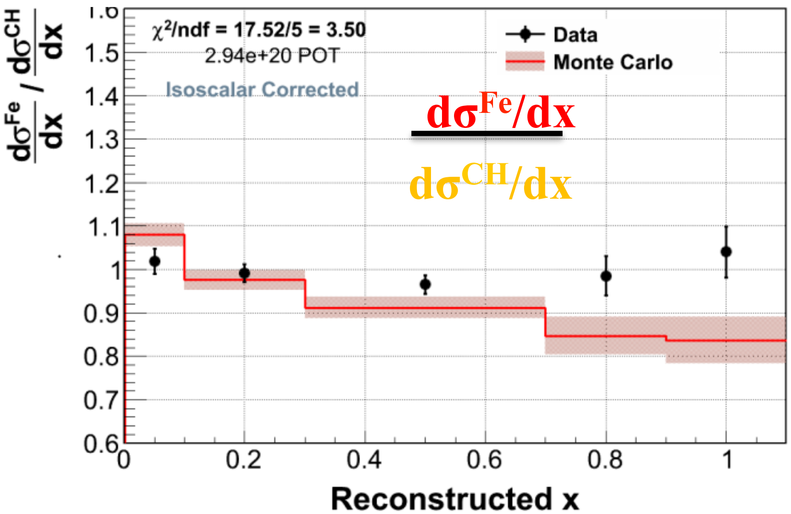
CTEQ prediction for the structure function ratios MINERvA can measure:

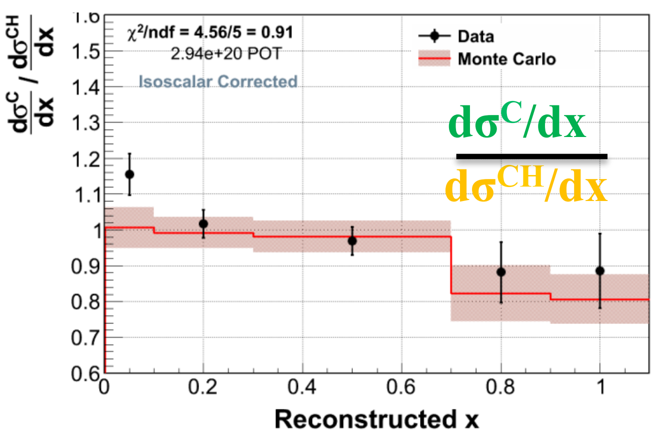


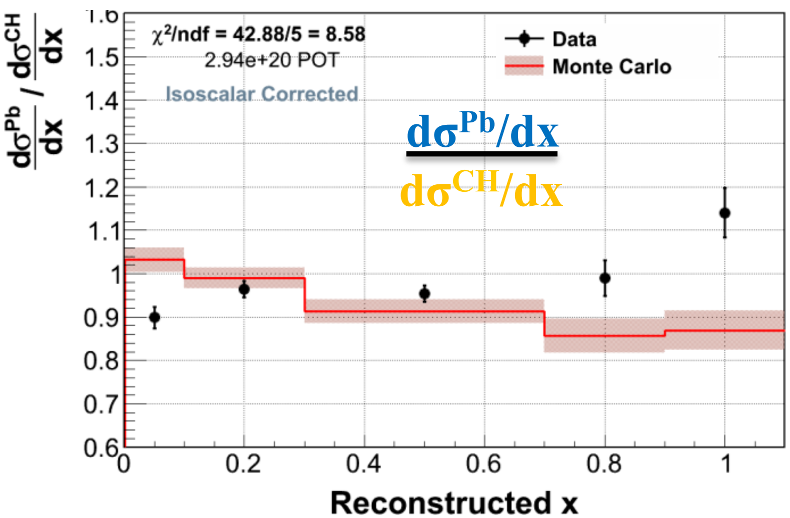
LE Cross Section Ratios as function of x



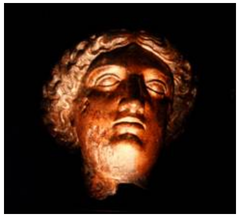
- At x=[0,0.1], we observe a deficit that increases with the size of the nucleus
- At x>0.7, we observe an excess that also increases with size of nucleus
- Data show effects not modeled in simulation
- Expectation from charged lepton data is that nuclear effects are smaller
  - But νs sensitive to xF_3
  - νs also sensitive to axial piece of F_2



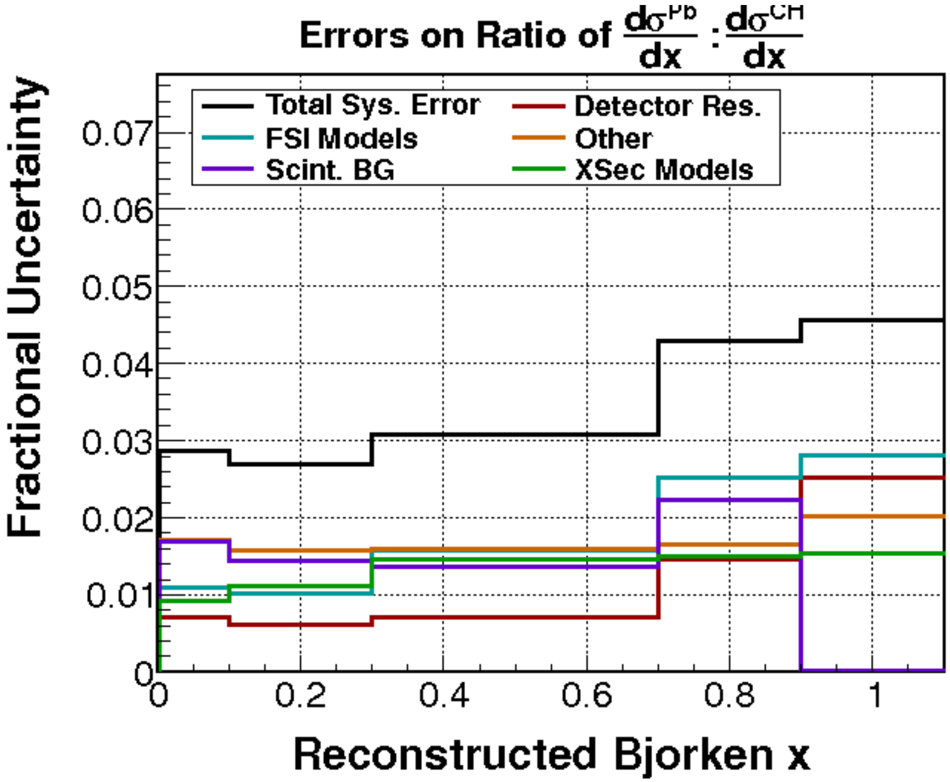




LE Nuclear Target Ratio Uncertainties



- Uncertainties similar across different solid targets
- Systematics low enough to see 10% effects at low x, need Medium Energy beam to get the needed statistics



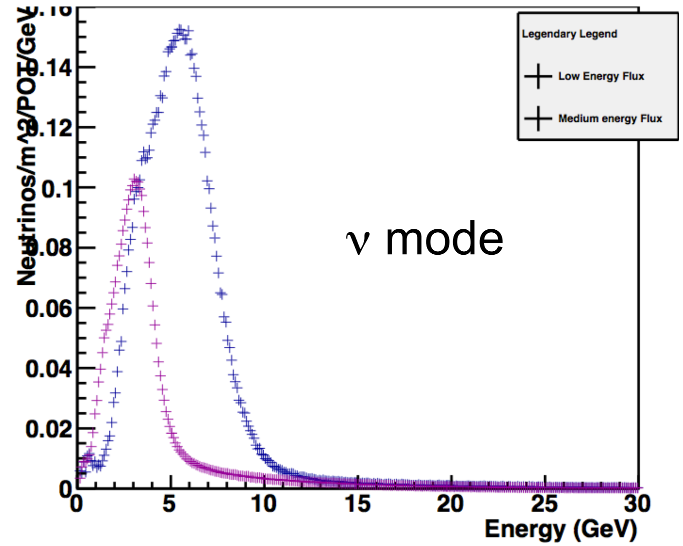
Expected Medium Energy systematic improvements:

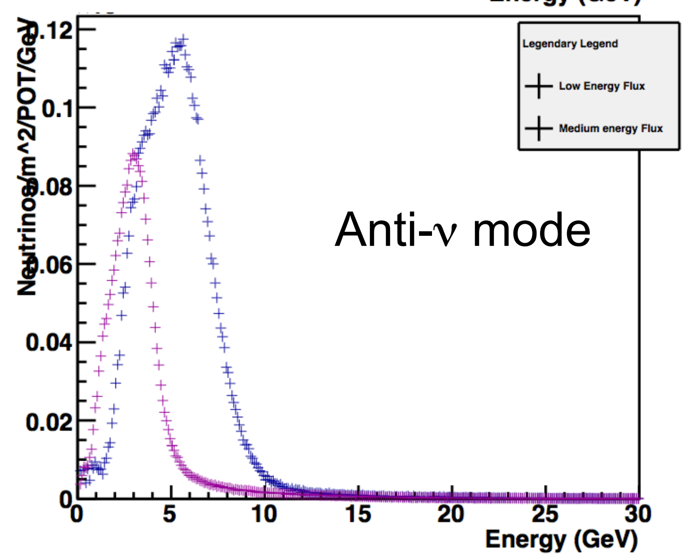
Improved Background Subtraction
Lower calorimetry systematics
Target ME systematic: 2-3%

Want finer x binning, so statistics goal is 10^4 events in current binning

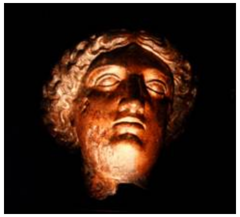
What Medium Energy Beam Brings

- More neutrino flux per proton on target (POT)
- More POT per year
- Higher energy ν's means (often) higher cross sections
- This means that where in LE run we could only measure events on scintillator, now we can think of getting results on nuclear targets too
- Will also get good statistics on Helium target (currently filling)

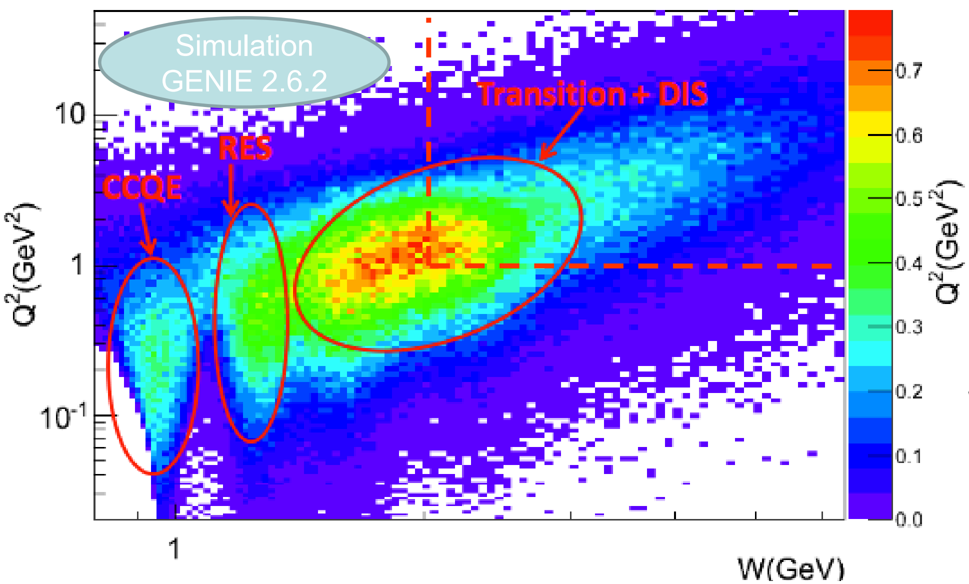


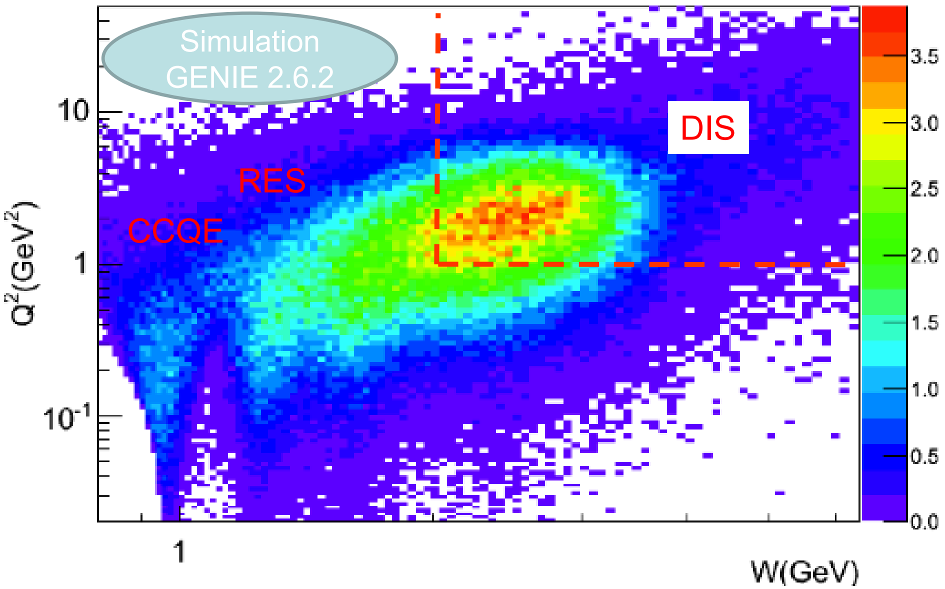


W, Q^2 regions in LE and ME beam

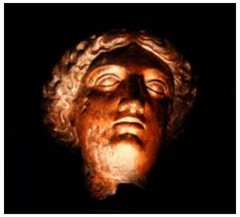


- Hadronic Invariant Mass (W) range and Q^2 both shift up
  - GENIE simulation, v2.6.2
  - Events shown have muon tracked in MINOS
  - See shift to lower x, fewer quasi-elastic and resonance events





Expected Statistics in Same x bins: Neutrino Mode



- Hit-level simulation on Medium Energy event sample, using cuts and reconstruction techniques from Low Energy analysis:

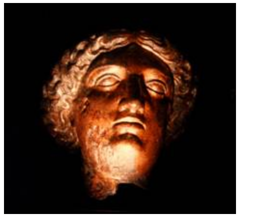
Bjorken x	0-0.1	0.1-0.3	0.3-0.7	0.7-0.9	0.9-1.1
Carbon	7.2	14.3	10.7	2.5	7.2
Iron	36.1	70.9	55.5	10.9	36.1
Lead	39.3	83.8	66.9	13.1	39.3
Scintillator	307.1	663.0	490.4	95.1	307.1

- ν kEvent rate for 6E20 POT for all events vs x (reconstructed x)

Ratio of events/POT ME / LE:

Bjorken x	0-0.1	0.1-0.3	0.3-0.7	0.7-0.9	0.9-1.1
Carbon	3.0	3.5	3.6	3.6	3.2
Iron	3.0	3.6	3.6	3.5	3.5
Lead	3.4	4.0	4.1	4.1	4.4
Scintillator	4.1	4.7	4.9	4.7	4.8

Expected Statistics in Same x bins: Anti-Neutrino Mode



- Hit-level simulation on Medium Energy event sample, using cuts and reconstruction techniques from Low Energy analysis:

Bjorken x	0-0.1	0.1-0.3	0.3-0.7	0.7-0.9	0.9-1.1
Carbon	4.5	7.3	6.2	1.2	4.5
Iron	20.8	34.4	27.5	5.7	20.8
Lead	21.5	37.8	28.0	6.1	21.5
Scintillator	174.3	325.0	260.6	56.3	174.3

Recall: goal of 10 kevents in these bins to be systematics dominated

Anti-ν kEvent rate for 6E20 POT for all events vs reconstructed x

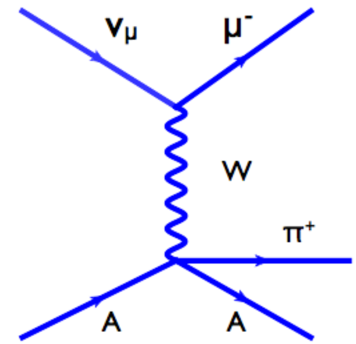
Bjorken x	0-0.1	0.1-0.3	0.3-0.7	0.7-0.9	0.9-1.1
Carbon	0.63	0.53	0.52	0.53	0.63
Iron	0.59	0.50	0.47	0.50	0.51
Lead	0.56	0.45	0.43	0.43	0.43
Scintillator	0.61	0.52	0.50	0.50	0.52

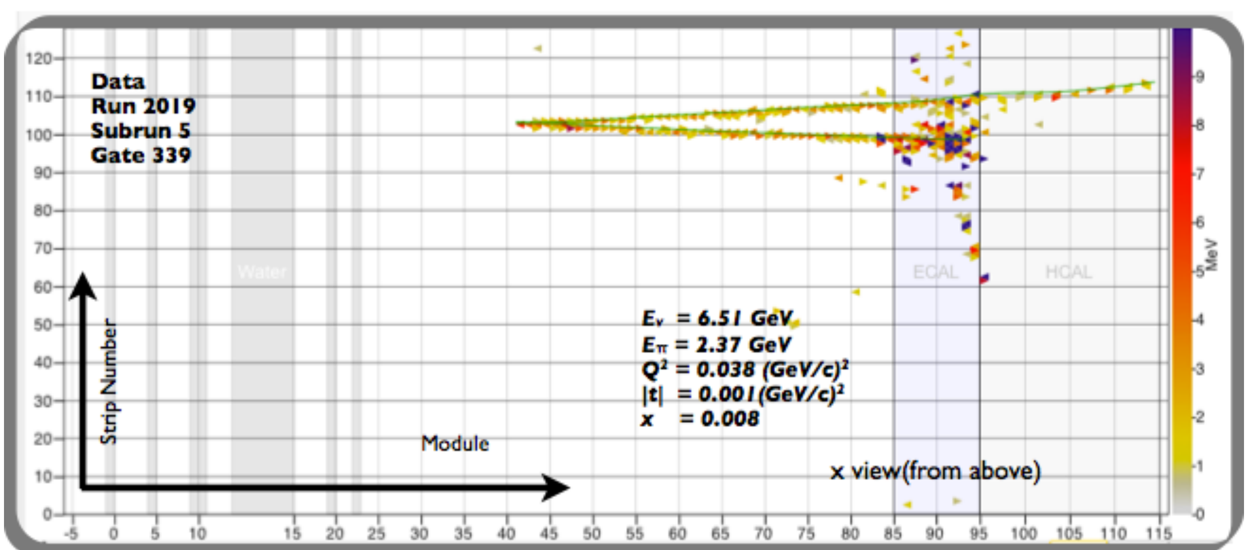
Ratio of anti-ν/ν Per POT n ME beam as function of measured x

Goal:
6E20 ν mode,
12E20 in anti-ν mode

Example: Coherent Pion Production

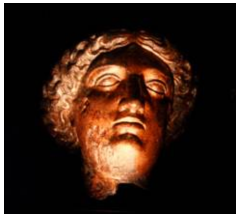
- Neutrinos can scatter off entire nucleus coherently
- Neutral Current channel is small background but with large uncertainties
- Puzzling history to this channel:
  - Seen in neutral current analog in many experiments
  - Not seen in charged current at ~1GeV but seen at higher energies
- Currently being explored in neutrino and antineutrino mode @ LE beam



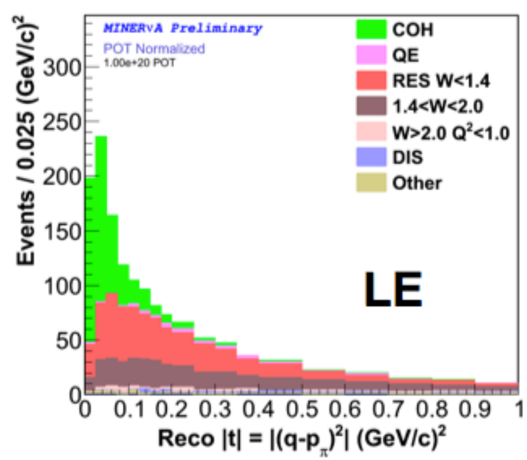


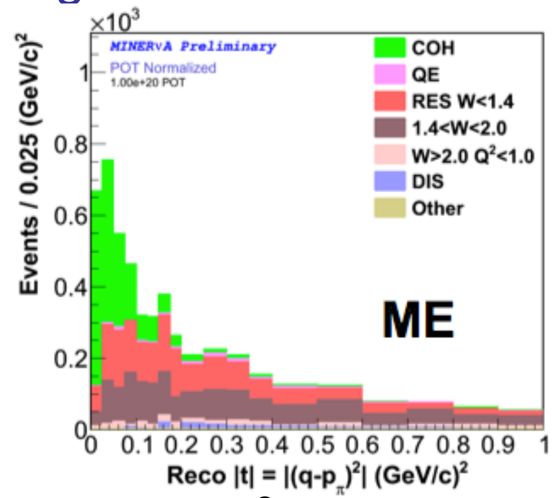
Candidate
From
Low Energy
Beam

Anti-ν Coherent Pion Production



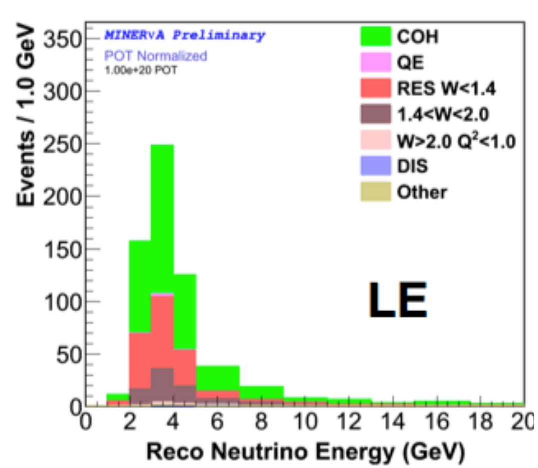
- Example: Anti-neutrino beam hit-level simulation, weighted for Medium Energy flux
- t distribution is how to distinguish signal from background: squared difference between momentum transfer to nucleus and final state pion momentum

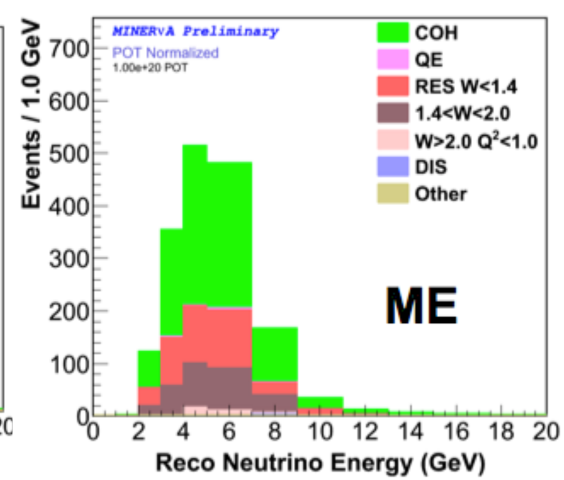




Cut at $t<0.1\text{GeV}^2$

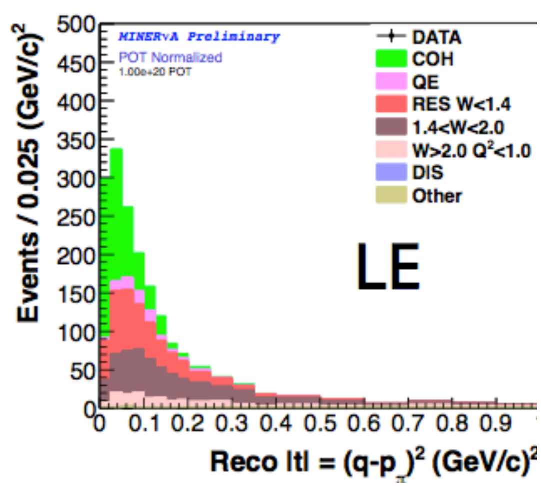
Beam Mode	Events (per 10^{20} POT)	Signal Purity	Stat error (at 10^{20} POT)
LE	716	57%	6.5%
ME	2430	58%	3.5%

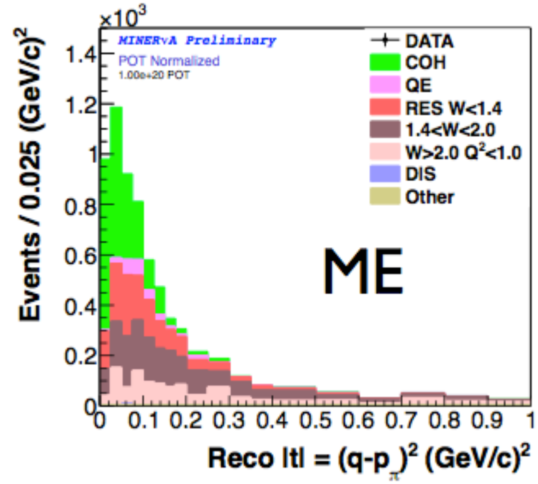




ν Coherent Pion Production

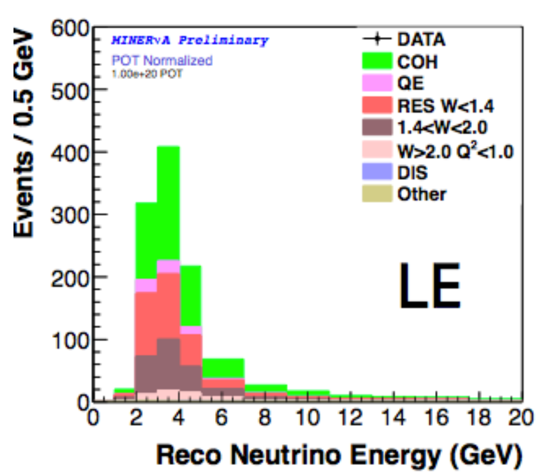
- Example: Neutrino beam hit-level simulation, weighed for Medium Energy flux
- Cut on t variable also valid, statistics better but background is a bit higher

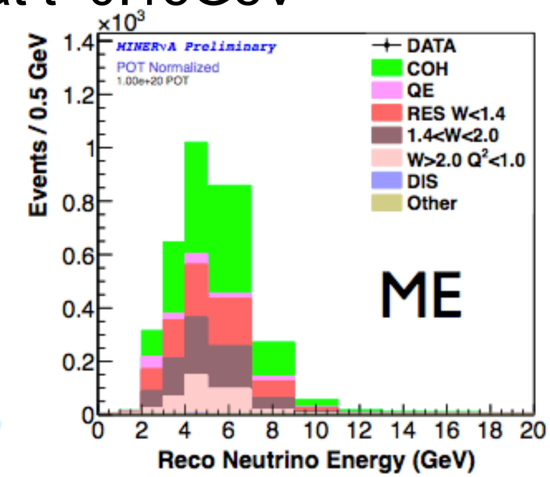




Cut at $t<0.15\text{GeV}^2$

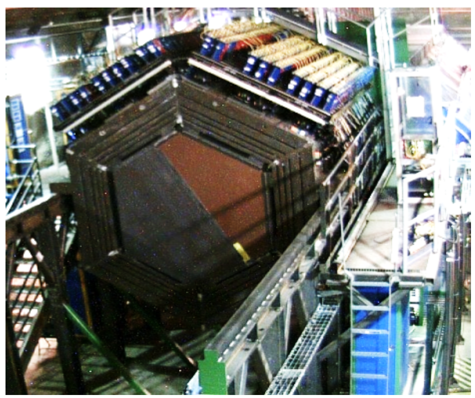
Beam Mode	Events (per 10^{20} POT)	Signal Purity	Stat error (at 10^{20} POT)
LE	1260	44%	6.4%
ME	4480	44%	3.4%

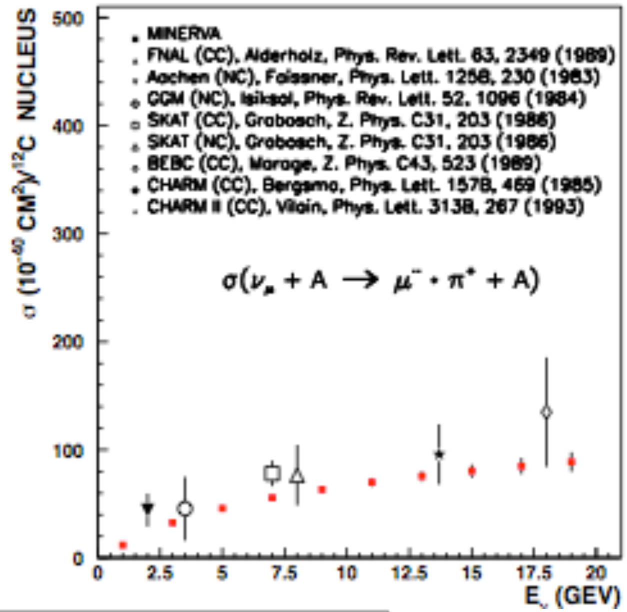




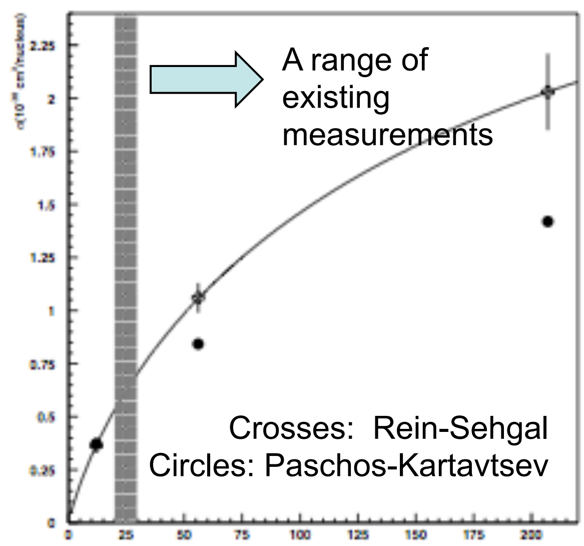
Coherent Pion Production off Nuclear Targets

- The event rate on scintillator can be scaled to most downstream Iron/Lead target (fiducial mass of either is about 3% that of scintillator)



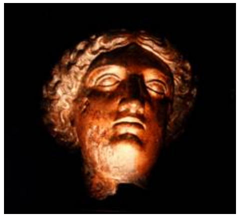


- With 6E20 POT in ν and anti-ν mode each we can make 8/9% measurements on coherent charged pion production in iron/lead (plot at right from MINERvA proposal)



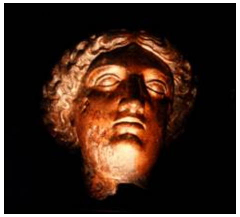
“SPECIAL RUNS” FOR FLUX DETERMINATION

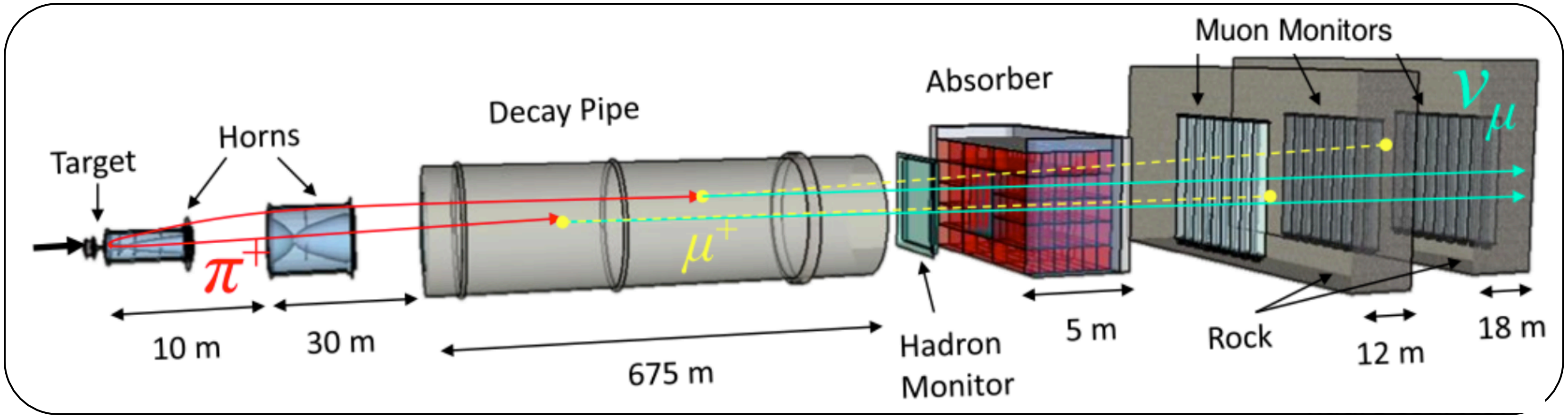
Special Run Request



- MINERvA is a cross-section experiment
- Flux enters directly into any absolute measurement we make
- These measurements will be used across many oscillation experiments, different fluxes, so getting absolute result per neutrino rather than per POT is crucial
- Big effort now to understand the Low Energy flux
- Took several runs in alternate configurations

Producing and knowing neutrino Flux

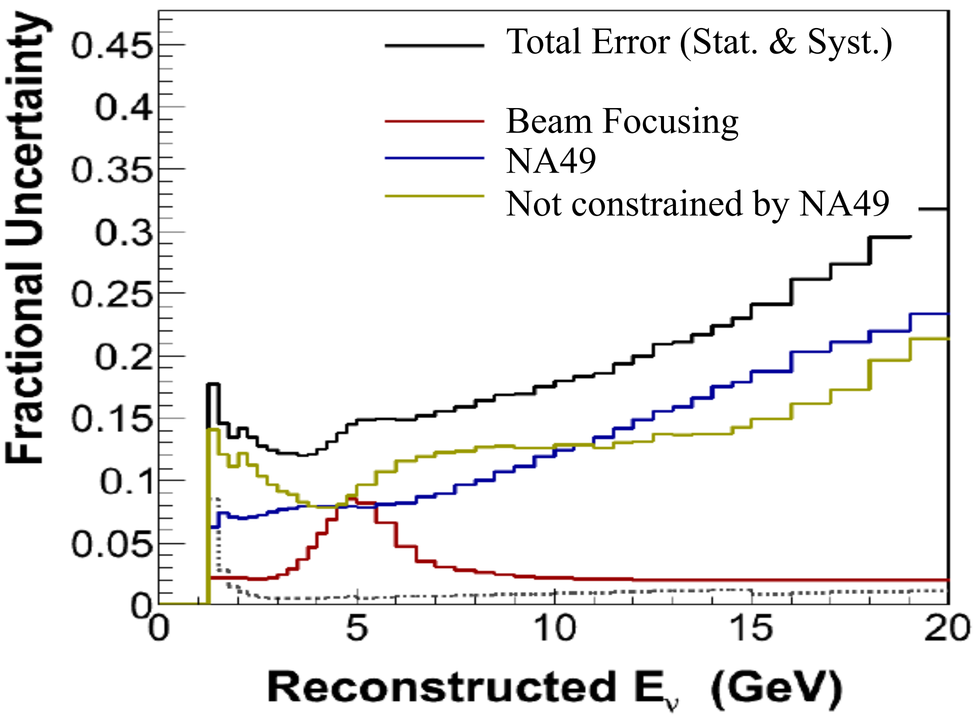


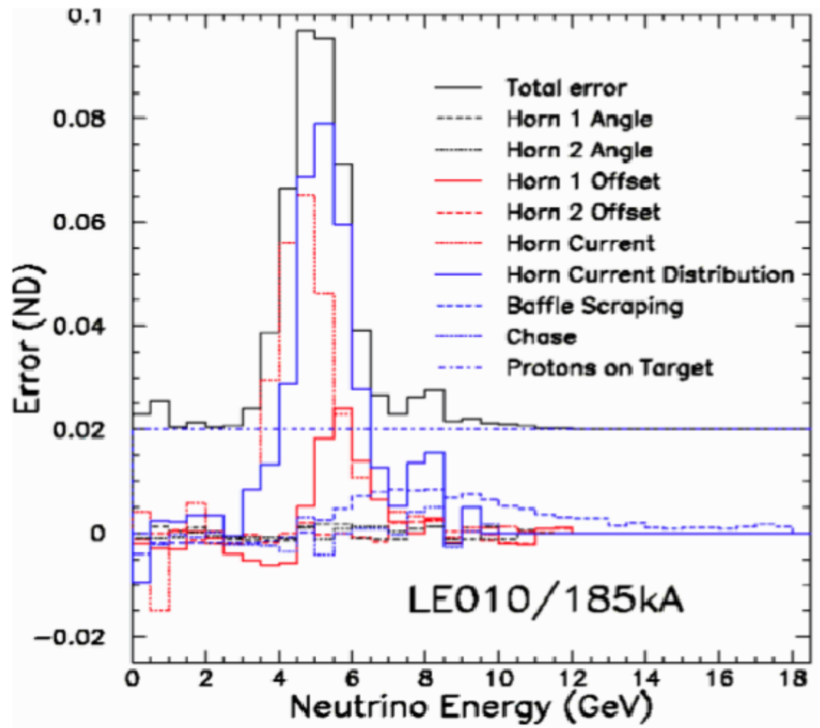


- Protons strike target, make pions and kaons
  - Need to understand hadron production for 120GeV protons on 2 interaction lengths of graphite
  - Use NA49 data as much as possible
- Pions and kaons focused by magnetic horn
  - Need to understand and simulate focusing elements
- Pions and kaons decay in beamline
  - Those pions and kaons sometimes reinteract in the beamline, need to understand tertiary production (production on Al, etc.)

Flux Uncertainties

- Different sources of errors produce different possible changes in expected spectrum
- Focusing errors tend to be on high side of focusing peak
- Overall level also uncertain, has always been for neutrino experiments





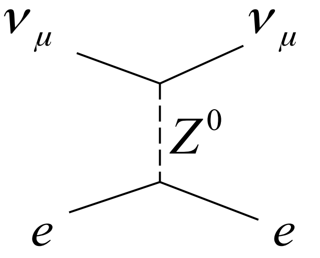
Z. Pavlovich, PhD thesis, UT Austin 2008

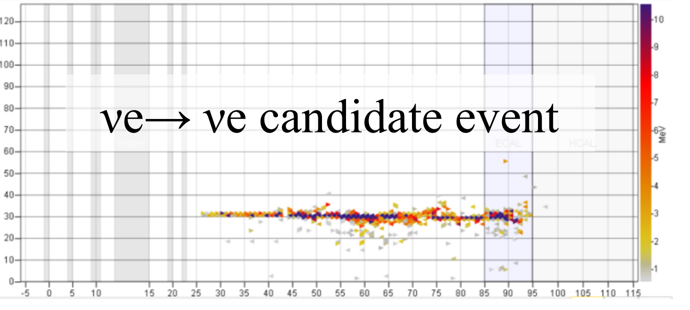
Constraint on Total Flux

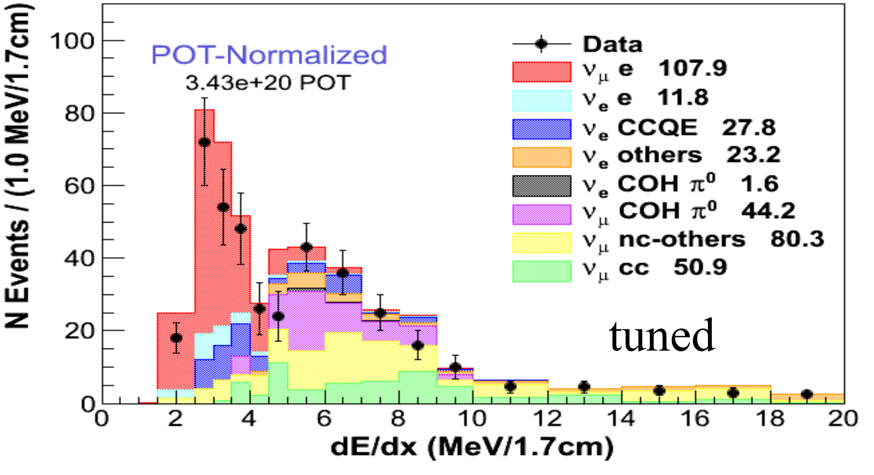
- Neutrino-electron scattering provides theoretically clean measure of total flux
- Signal at MINERvA relatively easy: single electron moving in beam direction
- Catch: process is 1/2000th the size of neutrino-nucleon scattering
- Need good angular resolution and electron ID
- Use dEdx at beginning of track candidate to isolate electrons from photons

$$\nu_\mu + e^- \rightarrow \nu_\mu + e^-$$

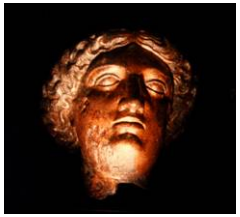
$$\bar{\nu}_\mu + e^- \rightarrow \bar{\nu}_\mu + e^-$$







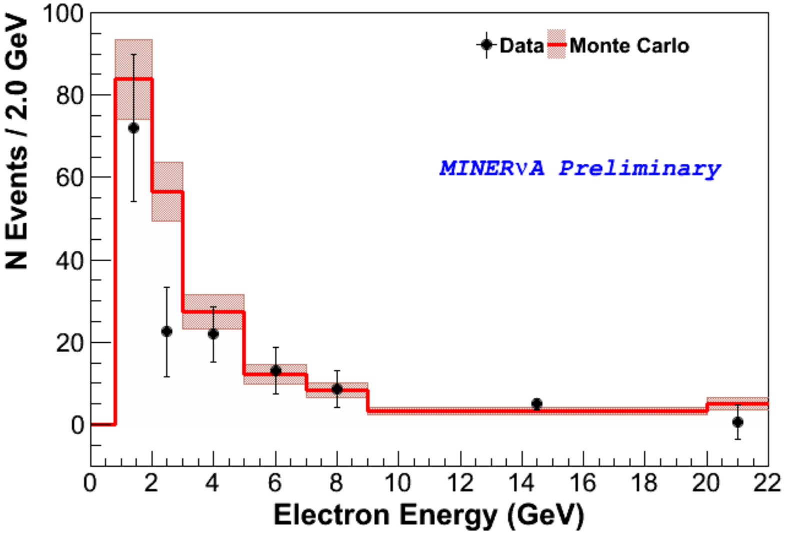
Neutrino-Electron Scattering Low and Medium Energy Beam

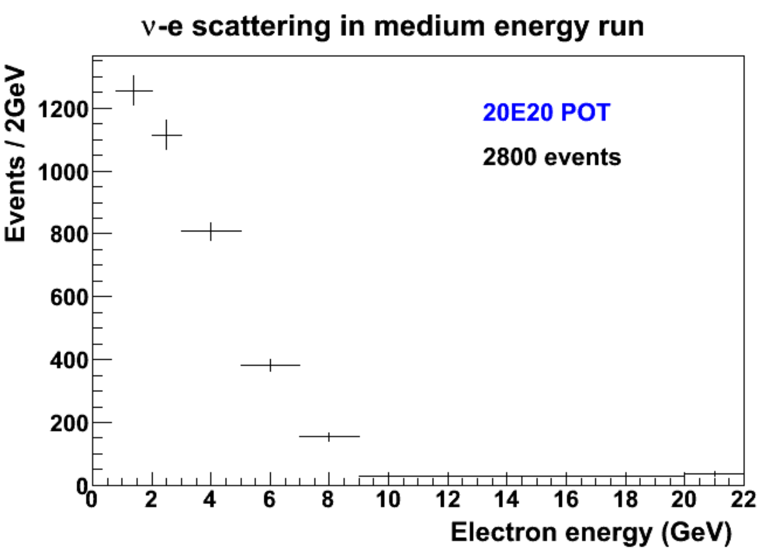


- ν-e scattering events after background subtraction and efficiency correction:

  123.8 ± 17.0 (stat) ± 9.1 (sys)

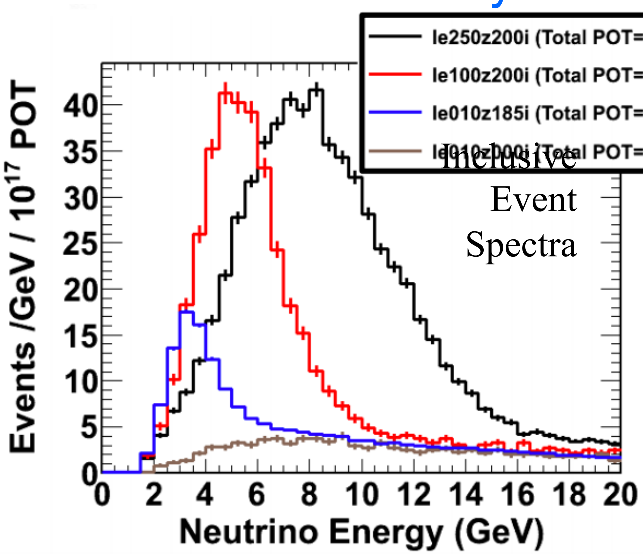
  total uncertainty: 15%
- Prediction from Simulation: 147.5 ± 22.9 (flux)
  - Flux uncertainty: 15.5%
- Expect similar signal/background ratio as in Low Energy Run:
  - Can expect statistical uncertainty of ~2%
  - Systematic uncertainty on this measurement is now 7% → 5% "easily"
- Could be the most well-constrained flux in history of neutrino beams
- Technique useful for Oscillation Experiments, constrains integral of flux*energy

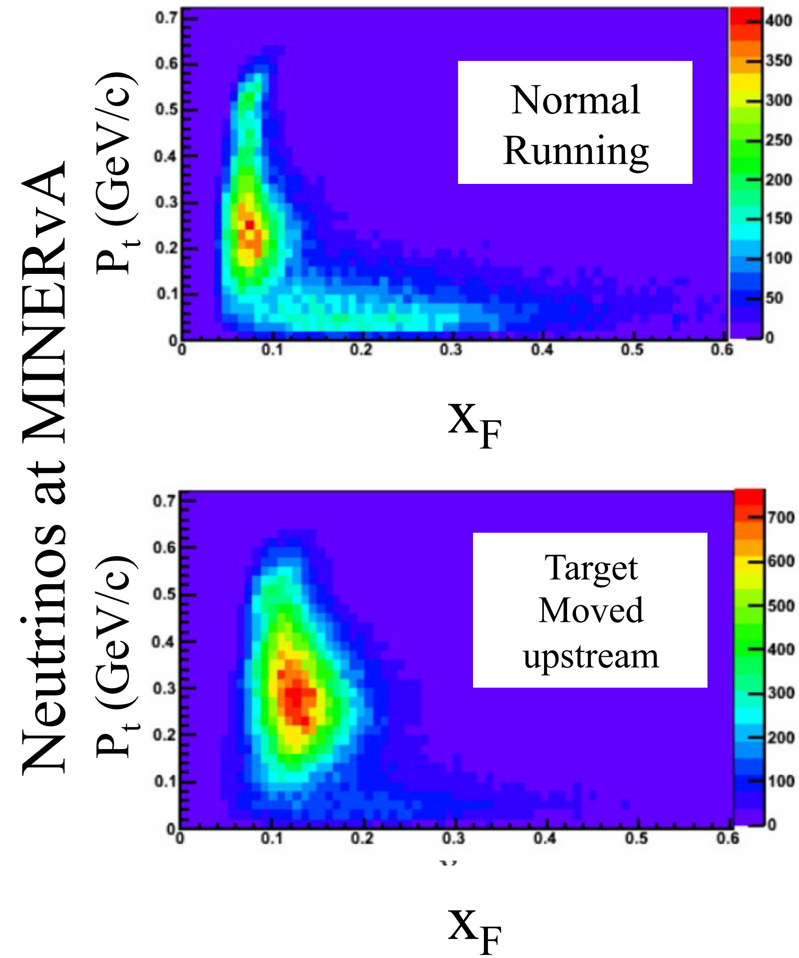




Getting to Neutrino Energy Spectrum: Special Runs to Understand Flux

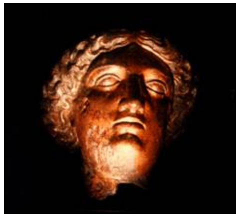
- By changing target position with same focusing elements, can disentangle focusing uncertainties from hadron production uncertainties
  - Different geometry focuses different parts of xF p_T space
  - MINERvA does this by using low hadron energy ν_μ charged current events, where energy dependence of cross section is very well understood





Pion Phase Space

Special Run History in LE beam



Play -list	Mode	Target	POT (E18)	PPP (E12)
1	LE FHC	NT03	94	varied
13c	LE FHC	NT07	117	36
7	LE FHC	NT06	2.5	18
9	LE FHC	NT01	6	24
5	LE RHC	NT05	100	34
10	LE RHC	NT02 (old!)	39	32
2	ME FHC	NT04	6	32
11	ME FHC	NT07	6	35
3	ME RHC	NT04	4	34
12	ME RHC	NT07	4	36
4	HE FHC	NT04	7	34
8	HE FHC	NT01	7	25
6	0 HC	NT05	5	34

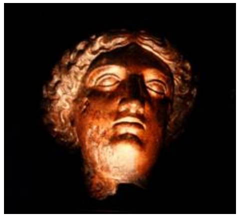
Notes:

Have several runs in same configuration, different intensities, different targets

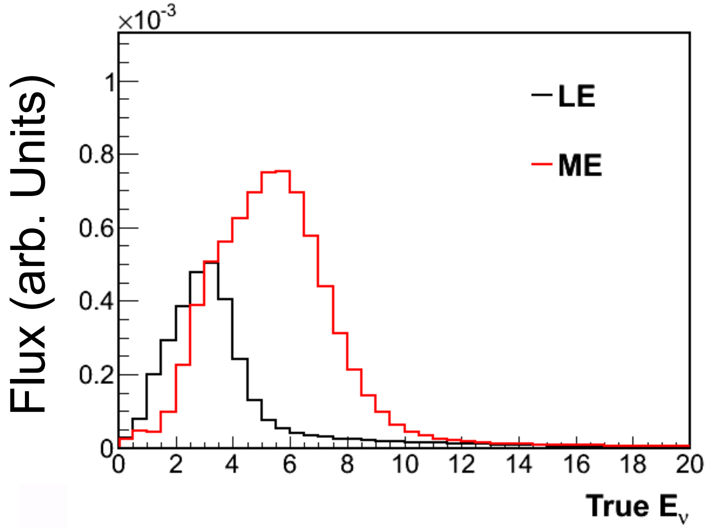
Very useful to have RHC and FHC in at least one special run

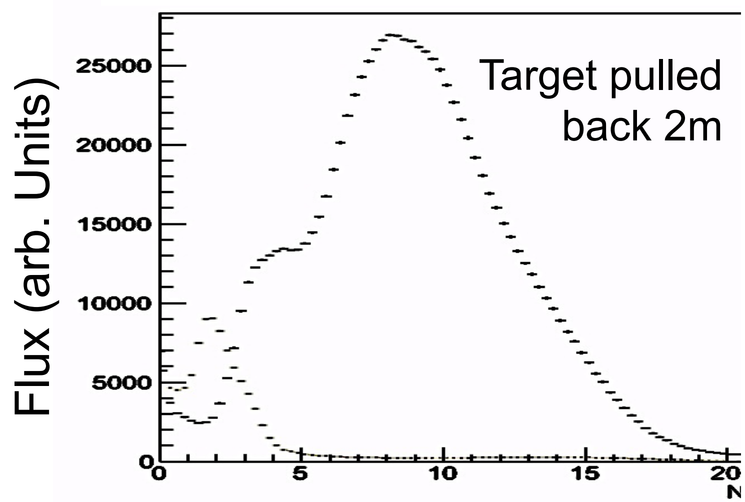
Usually asked for 7E18 POT, usually ended up with less because of downtimes

Medium Energy Special Run Request



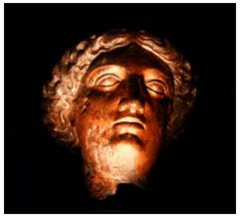
- In Medium Energy run, absolute cross sections are more the main focus of the experiment
  - Crucial for structure functions, need ν and anti-ν both
- Once again, existing external hadron production measurements are not sufficient
  - Need to understand role of tertiary production
  - Need to understand effects of beamline geometry
- Special runs with target moved back a substantial amount would allow two different x_F p_t regions in pion kinematic space to be focused by same horns
- Medium Energy target can be moved to specific location upstream of nominal position to provide new flux: peak energy goes from 6GeV to 9GeV
- Request: 7E18 protons on target in each mode (neutrino, antineutrino) with target pulled back 2m





Lower plot courtesy A. Schrechenberger

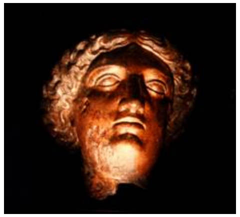
Conclusions



- MINERvA is already making important contributions to field of neutrino (oscillation) physics
  - Understanding role nucleus plays
    - Changing the interaction rates
    - Changing the final state particles
    - Changing the event reconstruction biases
  - Learning how to measure neutrino fluxes
    - New “standard candle” can be used with relatively cheap detector
- Need Medium Energy Beam to complete the broad physics program that we proposed to do
  - Nuclear effects on exclusive processes
  - Structure functions on different nuclei
  - 12E20 Protons on target, with at least 6E20 in antineutrino mode
  - Special run request of 14E18 in “high energy” configuration

BACKUP SLIDES

MINERvA Collaboration



~80 collaborators from particle and nuclear physics

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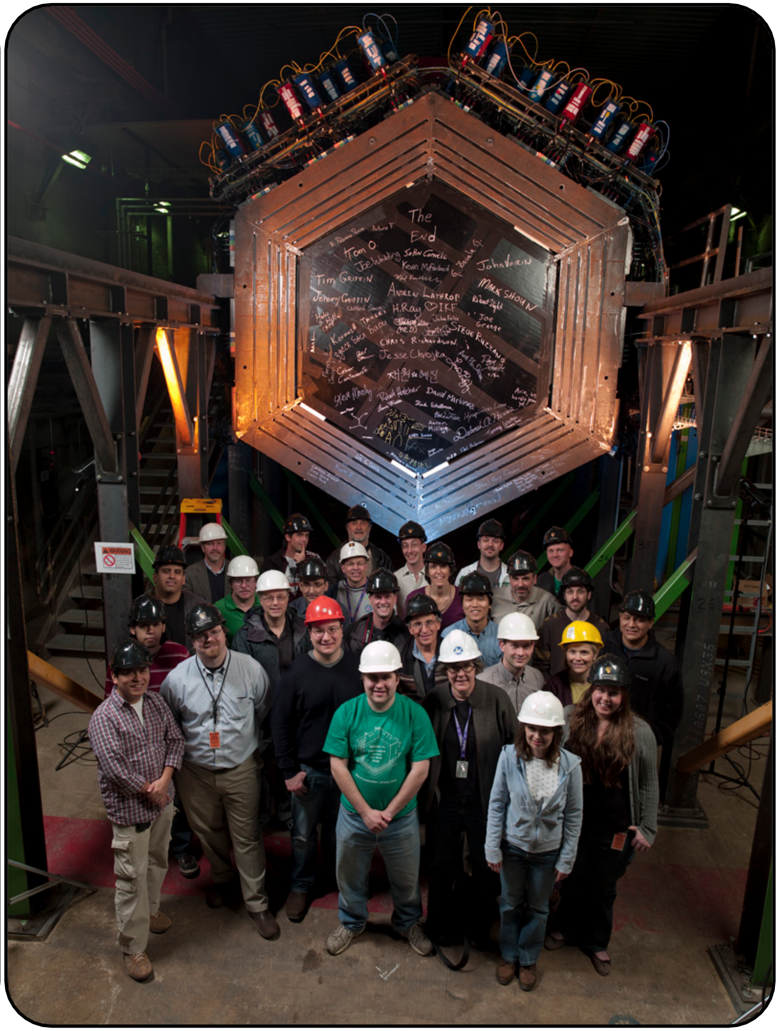
Fermilab
University of Florida
Université de Genève
Universidad de Guanajuato
Hampton University
Inst. Nucl. Reas. Moscow
Mass. Col. Lib. Arts
Northwestern University
University of Chicago

Otterbein University
Pontificia Universidad Catolica del Peru
University of Pittsburgh
University of Rochester
Rutgers University
Tufts University
University of California at Irvine
University of Minnesota at Duluth
Universidad Nacional de Ingeniería
Universidad Técnica Federico Santa María
College of William and Mary



Role of Anti-neutrinos

- Having both neutrinos and antineutrinos means we do better on structure functions
- Deep Inelastic Scattering event rates, even in Medium Energy Beam, still low, especially in anti-neutrino mode

Bjorken x	0-0.1	0.1-0.3	0.3-0.7	0.7-0.9	0.9-1.1
Carbon	0.1	3.1	1.0	0.0	0.1
Iron	0.4	9.4	3.0	0.0	0.4
Lead	0.5	11.4	3.7	0.0	0.5
Scintillator	5.5	116.0	41.0	0.1	5.5

Deep Inelastic Scattering kEvents for 6E20 POT

- Total event ratio (anti-ν/ν):

Bjorken x	0-0.1	0.1-0.3	0.3-0.7
Carbon	0.21	0.34	0.31
Iron	0.26	0.26	0.29
Lead	0.17	0.26	0.22
Scintillator	0.23	0.29	0.29

Ratio of anti-ν to ν event rates